DATA ACQUISITION

Eliminate the Effects of Lead-Wire Resistance

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For many years, the Wheatstone bridge has been an essential circuit for measuring microvolt changes in voltage-level signals. The classic 4-arm circuit is not, however, without limitations. It assumes that lead-wire resistances vary identically, something you can't always count on. Even when lead-wire resistances do vary identically, you can still get measurement errors because the lead resistances desensitize the measurement circuit.

You can eliminate the effects of lead-wire resistance by not including their IR drops in any sensed voltages, an impossibility with the Wheatstone bridge. This requires what I call a *dual-differential input circuit,* which can be made from two instrumentation amplifiers and which relies on the current being the same in all parts of a series circuit.

The dual-differential circuit reduces errors by simply not sensing any IR drops other than those of interest. In addition, the circuit produces an output that has twice the amplitude of the output of a Wheatstone Bridge and is linear for all changes in sensor resistance. You can use this circuit as a front end for DMMs and A/D converters when using RTD or strain-gauge sensors.

The dual-differential circuit (**Fig. 1**) uses two instrumentation amplifiers with one amp's output tied to the reference input of the other. Instrumentation amplifiers can deliver a desired voltage difference even when the voltage difference is riding on an undesired common-mode voltage. Instrumentation amplifiers can also be operated at unity gain, and their output can be referenced to any stiff (low-impedance) point such as another instrumentation amplifier's output. Operating instrumentation amplifiers at unity gain opens up untapped measurement possibilities for the versatile device.

Two Amps Are Better Than One

The two instrumentation amplifiers in Figure 1 form a dual-differential input circuit. Each amplifier operates at a gain of 1 because the gain-setting resistors have been omitted between pins 1 and 8. Therefore, the instrumentation amplifier's input voltage—from pin 3 (+) to pin 2 (–)—is reproduced at the output (pin 6) with respect to wherever you connect the output reference terminal (pin 5). The output reference terminal must be connected to a low-impedance point to preserve the instrumentation amplifier's common-mode rejection.

Input V_g connects to amplifier INA1 operating at a gain of +1. Input V_{ref} connects to INA2 operating at a gain of –1. Because of their high input impedances (typically $10^{10}\ \Omega$), the amplifiers draw essentially no current at their inputs through lead-wires RW_3 and RW_4. The connection to the inverting and noninverting inputs (pins 2 and 3) determine the polarity of the amplifier's output. The reference terminal (pin 5) of INA2 is connected to analog common and its output (pin 6) is connected to the reference terminal of INA1.

Lead-wire IR drops become a part of the common-mode voltages rejected by INA1 and INA2. The output taken from the output of INA1 is $V_g – V_{ref}$. The equations below show that the output yields the desired result, namely $I\Delta R$ within the accuracy of INA1 and INA2. Because wire resistance does not appear in the system equations, the output is

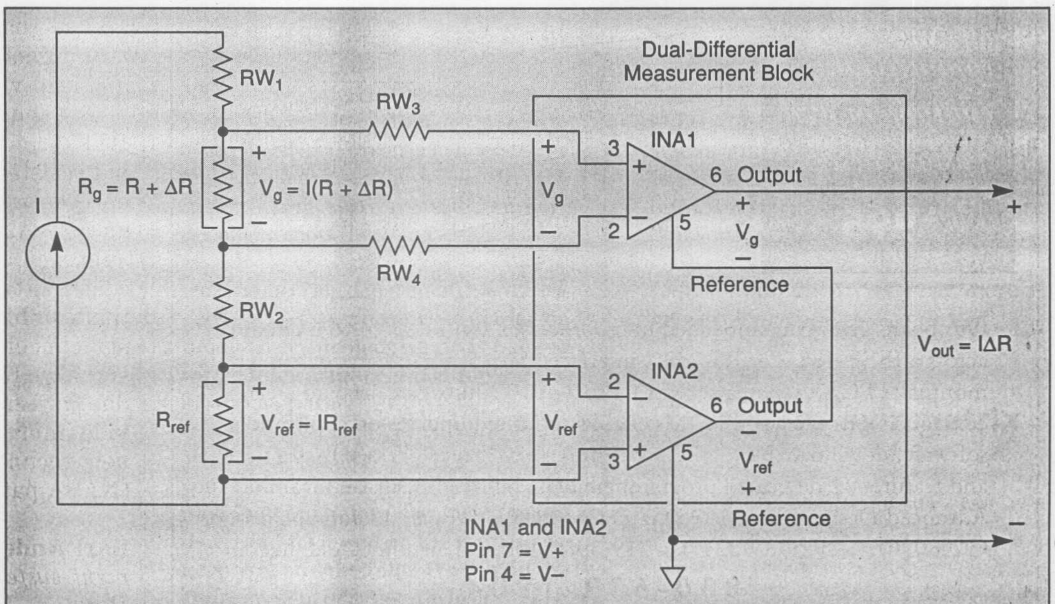

FIGURE 1. A dual-differential circuit measures ΔR by subtracting the voltage created by a reference resistor from the voltage created by the sensor resistor.

theoretically insensitive to *any* lead-wire resistance change:

$$V_{out} = V_g - V_{ref}$$
$$V_{out} = I(R + \Delta R) - IR_{ref}$$

If $R_{ref} = R$,

$$V_{out} = I(R + \Delta R) - IR$$
$$V_{out} = I\Delta R$$

Be careful when choosing an instrumentation amplifier for dual-differential input circuits. After all, the circuit must subtract volt-level signals with microvolt-level stability

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and accuracy. If you are operating at unity gain, the output-referenced errors of the amplifier may seriously degrade the performance of the circuit. Common-mode rejection improves with the amplifier's gain. I have had good results with INA114 instrumentation amplifiers because of their high common-mode rejection (>75 dB at unity gain) and almost no output-referenced error.

Using the INA114, each ohm of random lead-wire resistance change appears as a few micro-ohms of apparent transducer output in the output voltage. Therefore, you can use the circuit as a strain-gauge or RTD signal conditioning circuit that is unaffected by random changes in *any* lead-wire resistance.

You must pick R_{ref} to equal your RTD or strain-gauge sensor's nominal resistance (R). The initial difference between R and R_{ref} appears as an offset in the output that you can subtract out using your meter or a computer. You can add circuits that combine current regulation, offset canceling, self-calibration, and signal-validity identification to the dual-differential circuit. I can provide information about licensing this new technology for commercial use (NASA patent no. 5,371,469). *T&MW*

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